"AQUA PURA"

Don Arnold, Ch. E., 3

"Aqua pura" the ancient Romans called it. To the chemist it is hydrogen hydroxide or H_2O. To John Q. Citizen it is just plain water. He uses it to quench his thirst, wash and keep clean in, and to water his garden, among other things. Nevertheless, without it, life as we know it would be impossible. At first, man, living near a body of water as was his custom, would merely go down to the shore and secure the water as he found need for it. The washing was even done in the stream or lake itself.

The Industrial Revolution and its increase of metropolitan areas resulted in a considerable problem of obtaining water supplies. Many of the epidemics of the past centuries resulted from contaminated water supplies. From this danger has gradually evolved the systems of water treatment in use today.

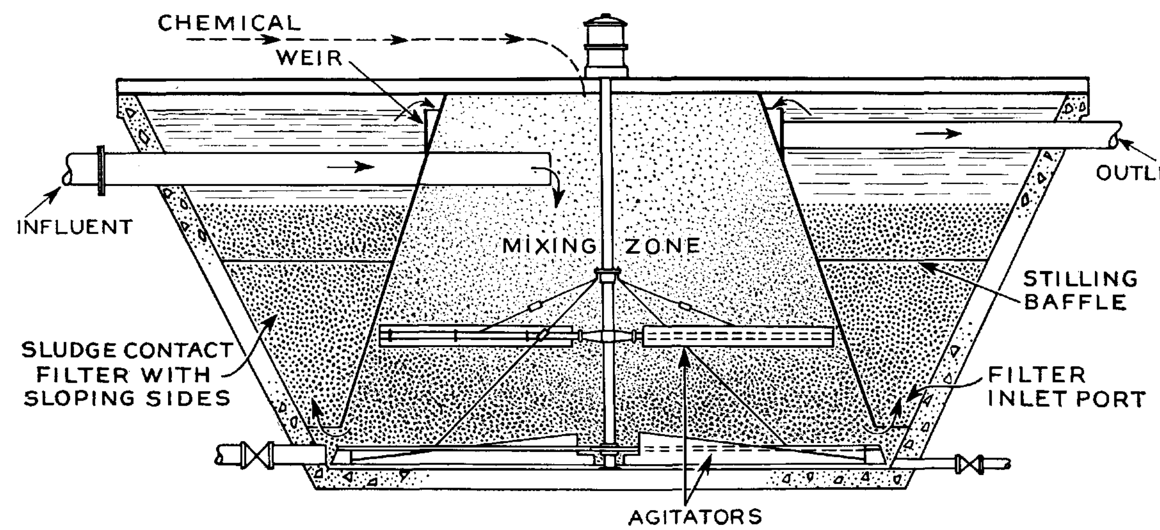
A satisfactory public water supply must contain a minimum of organisms which produce disease. It must be sparkling clear, colorless, good tasting, free from odors, reasonably soft, free from objectionable gas and minerals, neither scale forming nor corrosive, plentiful, low in cost, and preferably cool. These conditions confront the engineer even before he has found a source of water. Some of the conditions may be remedied by treatment in the "water-works" but this imposes an additional expense. Since nature very rarely provides a supply which meets all these specifications, it is necessary that the best one available be selected and treated to produce the desired qualities that are found lacking.

The earliest method was to permit the water to stay for long periods in storage basins and reservoirs. The disadvantages of this system are the high initial cost of the reservoirs and basins and the tendency of the water to become stagnant.

A second method is the slow sand filtration. This method requires filtration through one-acre beds of sand 30 to 40 inches deep. To obtain satisfactory results with this equipment it is necessary that the water source have a low turbidity and a low color content. The defects of this system are the high expense of the filter construction, the large area required, and the need of a special water supply.

The most widely used plan is the rapid sand filtration which involves chemical treatment previous to the filtration. The water is first aerated to free it from dissolved gases, to oxidize the iron into the insoluble form (ferrous to ferric), and to oxidize the organic matter. This processing may be accomplished by spraying the water from nozzles, allowing it to flow over cascades, or permitting it to trickle through coke trays. The first is the one most generally practiced.

A coagulating chemical that dissociates in alkaline water to form a gelatinous, sticky precipitate which absorbs color and entangles mud, bacteria and suspended matter is added to the aerated water. Ferric sulphate, chlorinated ferrous sulphate, ferric chloride, aluminum sulphate, sodium aluminate, lime, or a combination of ferrous sulphate and lime may be used as the coagulating agent. The choice depends upon the



Gravity Filter

Courtesy National Lime Assn.

alkalinity and organic content of the water to be treated. Aluminum chloride, chromic chloride, and titanium tetrachloride may be used for this purpose but are of no practical use at present, because ferric chloride serves the purpose more economically.

The general principle of this coagulation is demonstrated by the application of aluminum sulphate which forms aluminum hydroxide, a reaction familiar to every general chemistry student. The lime is used where sufficient magnesium is present to precipitate as $Mg(OH)_2$ which acts as the coagulating agent.

These chemicals are given a violent and momentary mixing with the water, thirty minutes to an hour of gentle agitation, and finally about six hours of settling in the sedimentation basins. The agitation is performed by means of rotating paddles or propellers, diffused air supplied from a compressor, or a flocculator which is an improved type of paddle agitator.

The finer particles which do not settle are removed by a sand filter. The gravity filter is composed of a concrete box with 18 to 24 inches of gravel covering the outlet pipes which is in turn covered with 24 to 30 inches of filter sand. There is a wash trough suspended above the sand. It carries away the wash water after it is forced back through the filter. This washing removes the filtered matter and loosens the sand.

The pressure filter consists essentially of the same construction as the gravity filter but is built in a metal shell rather than in a concrete box. In this manner, the pressure of the pump bringing the water to the filter is maintained for pressure in the mains whereas a second pump is required for this purpose in the case of the gravity filter. The disadvantage of the pressure filter lies in the impossibility of thoroughly and conveniently inspecting the filtering material and in the low wash-water efficiency.

The danger of infection by the bacteria is removed by disinfection and sterilization. Chlorine has generally been used for this purpose. In the early days it was supplied by the application of chloride of lime. Later, electrolytic cells were tried and abandoned. At the present time the liquid chlorine supplied in steel cylinders is in use. Hypochlorites are found to be valuable in emergencies. Where a high residual concentration of chlorine is required either a chloramine or an excess of chlorine is used. Ammonia and chlorine are added to the water separately to combine into the chloramines in the water.

$$3Cl_2 + 2NH_3 = 2NHCl + 4HCl$$
$$Cl_2 + NH_3 = NH_2Cl + HCl$$

The chloramines are relatively tasteless and a higher concentration may be maintained without introducing the chlorinous tastes.

When an excess of chlorine is used, dechlorination with sodium thiosulphate, sodium sulphite, sulphur dioxide, or activated carbon is necessary.

It has been found that lime-softening kills the bacteria sufficiently to eliminate the need for further disinfection.

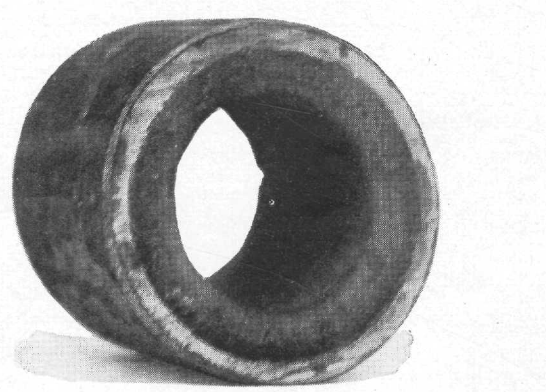
The alkalinity and the amount of calcium carbonate must be controlled to prevent the solution of the iron of the pipes of the distribution system and subsequent corrosion of these pipes. Water with a pH (hydrogen ion content) of 9 dissolves very little iron while a lower pH results in enough dissolving to produce "red water". When the water is saturated with $CaCO_3$, a protective coating of the $CaCO_3$ is deposited on the pipes. If the saturation drops this coating is dissolved. Therefore a definite pH and $CaCO_3$ must be maintained in the water supply as delivered to the consumer.

This control of carbonates leads the researcher to the modern topic of water softening. In 1766 Cavendish noticed the reaction which is the basic process of our present softening system, namely the deposition of carbonates from water supplies. Thomas Henry in England proposed the use of the lime softening process in a large plant scale in 1800, but it was not until 1841 that Dr. Thomas Clark patented the process of removing earthy carbonates from water supplies by adding lime.

$$Ca(HCO_3)_2 + Ca(OH)_2 = 2CaCO_3 + 2H_2O,$$
$$Mg(HCO_3)_2 + 2Ca(OH)_2, = Mg(OH)_2 + CaCO_3 + H_2O$$

The process was developed on the demand of a number of the new stream-powered industrial plants. The first municipal softening plant in the United States was installed in Oberlin, Ohio in 1903. Many public and private plants using the Clark process have been constructed since that time.

The hardness of water is considered in two classes: carbonate and non-carbonate, formerly called temporary and permanent respectively. The first class is composed of bicarbonates of calcium and magnesium. In the latter class is calcium sulphate, commonly known as gypsum, and magnesium sulphate, the druggist's



Courtesy National Lime Assn.

Scale Formation in Pipe

epsom salts. In addition to these minerals, iron and aluminum compounds are found to be objectionable.

The most extremely hard water is found in Ohio, Indiana, Illinois, Iowa, South Dakota, Nebraska, Kansas, Arizona, Florida and part of Pennsylvania. Compiled charts demonstrate the variation in the hardness of water supply of the United States.

The minerals which make water hard are undesirable due to the formation of soap curds by the calcium and magnesium ions uniting with the soap. This curding results in a precipitate in the wash water and a wastage of soap in actually softening the water before any washing may be accomplished. Furthermore the carbonates precipitate out in hot water pipes and boilers causing a loss in heat efficiency. According to a report of the U. S. Bureau of Mines, the heat loss (this is really not a heat loss but a reduction in thermal conductuity of the pipes) due to scale 1/50 to 1/9 inch thick amounts to from 7 to 16%.

Soap Wastage and Cost When Using Water Having Hardness Varying From 150 to 500 Parts Per Million

Raw Water P. P. M.	Hardness Removed by Softening	Hardness Reduced to	Loss in Lbs. Soap Per Family of Five Per Year	Loss of Family of Five Per Year*
150	65	85	28.5	$ 3.40
200	115	85	50.0	6.00
250	165	85	72.5	8.70
300	215	85	94.0	11.30
350	265	85	116.0	13.90
400	315	85	138.0	16.55
450	365	85	160.0	19.20
500	415	85	182.0	21.85

*—Soap at 12 cents per pound.

This table compiled by Charles P. Hoover from three different surveys of the effect of water softening.

One of the more important processes of softening is the lime and soda ash method. The lime and soda ash are added to the raw water either gravimetrically in the dry form or volumetrically in milk of lime or in solution. Where there is a storage problem as in small plants, the hydrated lime is used. In larger plants the quicklime (CaO) is used as it is more economical. They are often mixed, agitated, and settled in a manner similar to the purification treatment. Alum ($Al_2(SO_4)_3$) is used as a coagulating agent. After settling and filtering, sodium hexametaphosphate is added.

This use of calgon, as it is called commercially, is a new development known as the Threshold Treatment. The chemical has an unexplained capacity to keep the minerals which produce hardness in solution thus making the water soft although the minerals are present. It is especially important in preventing boiler scale but is harmless to even the finest fabrics and cloths.

A new development in precipitating machinery, the Permutit Spaulding Precipitator, reduces the time of treatment from five hours to one hour or less. No settling takes place due to the substitution of two fundamental chemical and hydraulic principles. The water and chemicals are introduced at the top center of the precipitator. As the mixture descends it is further mixed and brought into contact with the precipitate from the water which has just passed. This presence of the solid state with the precipitating solution increases the speed of coagulation. These particles act as nuclei for the smaller particles.

As the water continues to flow to the bottom, the paricles grow larger, settle, and leave the smaller ones to act as new nuclei to continue the process. The mixture is continuously agitated. When the water reaches the bottom, it passes through a small outlet around the outer edge and flows upward through the outer, V-shaped tank. This tank has a bed of sludge supported by the upward flow of the water. This acts as an upflow filter and removes much of the remainder of the precipitated matter. Clarification is obtained by reducing the upward velocity until it will no longer maintain sludge suspension. The water is taken from the top to the filters. The V-shaped design of the outer tank provides this reduction of pressure and also maintains a uniform composition of the filter bed.

The general design has been found to be so flexible as to be applicable to existing settling tanks and basins.

The advantages of this precipitator are many. It, as previously stated, cuts the time of treatment. Due to the action of the sludge in increasing the precipitation, less chemicals are required which in turn reduces the need for recarbonation. The sludge suspension system provides fresh sludge; the older particles settle to the bottom and are blown out a drain pipe. It automatically adjusts itself to varying rates of flow by raising or lowering the height of the filter bed. (This is actually done by the velocity of the water itself.) Longer filter runs are permitted due to a better job of particle removal done by the filter bed of sludge. The presence of particles in the sludge filter automatically provides the balance required for the protection of the distribution system.

In the lime-soda process the lime precipitates the hardness minerals while the soda ash and CO_2 of the recarbonation counteract the excess lime used.

A variation of this is the overtreatment of a portion of the water and mixing this with another part of the raw water. This is known as the split treatment.

Aluminum sulphate is added to decrease the time required for coagulation of the precipitate as well as to remove the soluble magnesium salts as insoluble magnesium aluminates.

The second method consists of replacing the calcium and magnesium with sodium which will not produce the reactions of the hard water but rather remains in solution. This is accomplished by the use of

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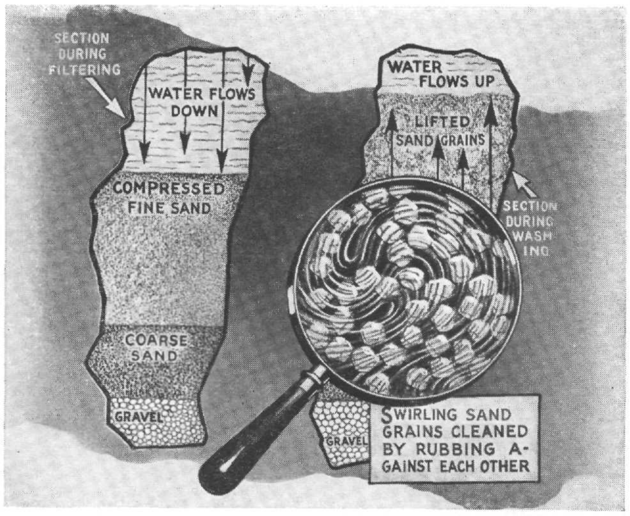
zeolites, which are complex insoluble mineral compounds of double silicates of aluminum or iron or both. They are found naturally as the greens and zeolites and are manufactured synthetically.

The zeolites are used as filter sand in both gravity and pressure type filters, the latter type being commonly used in the home and small shop. As the water flows through the sand, the Na replaces the Ca and Mg. The sand also filters out the suspended particles. After a period of time, the Na is all replaced and the sand is said to be exhausted. To regenerate it, it is merely necessary to pass a salt, ($NaCl$) solution through the sand. This reverses the process and the sodium replaces the calcium and magnesium which are washed out as soluble chlorides. This filter with the necessary regenerations may be used indefinitely.

One practical example of municipal softening in action is the plant at Orrville, Ohio. It was built in the summer of 1940 at a cost of $37,000 financed by a village bond issue. It is a lime-soda ash type treating water from two wells which has a hardness of 300 parts per million. The lime treatment reduces this to 92 in the settling basins. (It first passes through the mixing tank and the clarifier where it is agitated after the chemicals are added and mixed). The recarbonation reduced it further to 82 and the filter to 60. After the addition of the sodium hexametaphosphate and passage through the distribution system, it emerges from the tap with a hardness of 54 parts per million. After several months it was found that recarbonation was unnecessary with the elimination of overtreatment with lime and was consequently abandoned. The use of lime softening also eliminated the use of chlorine in the purification of the water. The sludge is used to flocculate the sewage diminishing the amount of ferric chloride and ferrous sulphate used there.

The averages of one month showed the average daily treatment of 420,000 gallons of water treated with 26.3 pounds of alum, 926 pounds of lime and 2 pounds of calgon. All of the reagents are first dissolved in water then added by automatic machinery.



Diagramatic View of Filtering and Washing Operations

In this plant 250,000 gallons were treated the first month at a cost of $20.20 per million gallons for chemicals. One year later the consumption had been boosted to 400,000 gallons per day and the cost of chemicals reduced steadily to $12.71 per million gallons, each successive month being lower than the one preceding it.

By a careful control of the reagents, the taste has been maintained and there has been a definite improvement in the performance of the home water-heating systems and a reduction in the soap consumption.

This brief description will give an idea of the advances made by engineering in the provision of water supplies for the general public. It is even more interesting to note that most of this progress has been made in the past century. References:

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Permutit Company, 330 W. 42nd St., New York, N.Y.

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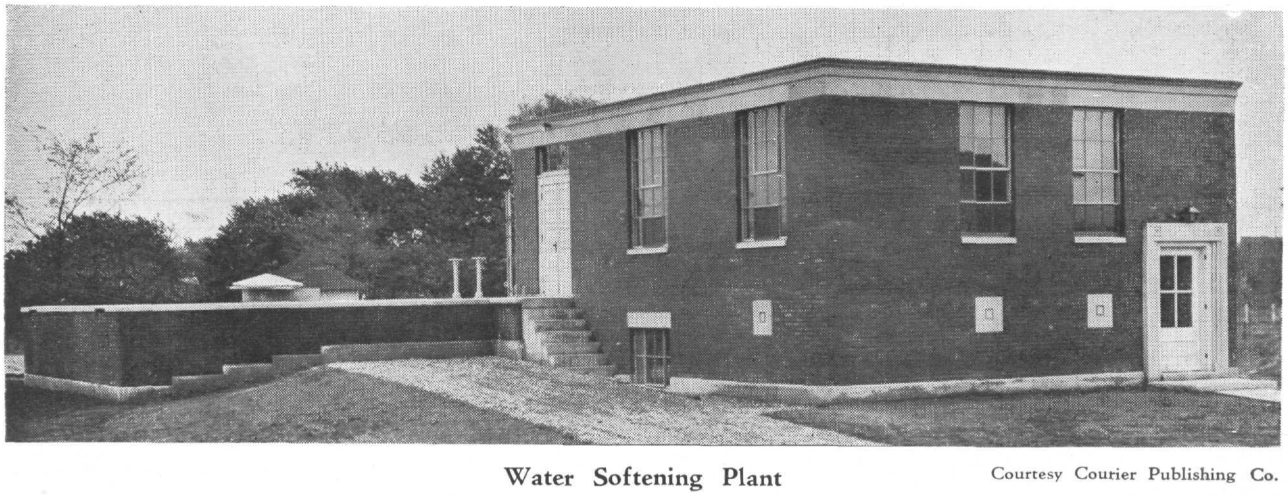

Water Softening Plant Courtesy Courier Publishing Co.